CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-114

March 4, 1981

1. Name of Fault

Calaveras fault and Busch Ranch fault.

2. Location of fault

San Felipe 7.5 minute quadrangle, San Benito and Santa Clara Counties (figure 1).

3. Reason for evaluation

Part of 10-year fault evaluation program (Hart, 1980).

4. References

Armstrong, C.F., 1979, Coyote Lake earthquake, 6 August 1979: California Geology, v. 32, no. 11, p. 248-251.

Armstrong, C.F., Wagner, D.L., and Bortugno, E.J., 1980, Movement along the southern Calaveras fault zone as shown by fence line surveys: California Division of Mines and Geology Special Report 140, p. 29-39.

Armstrong, C.F. and Wagner, D.L., 1978, Environmental geologic analysis of the Diablo Range, study area I, southern Santa Clara County, California: California Division of Mines and Geology Open-file report 78-11SF, scale 1:12,000.

Dibblee, T.W., Jr., 1975, Geologic map of the Hollister, Gonzales, and San Benito quadrangles: U.S. Geological Survey Open-file Map 75-394, scale 1:62,500.

Earth Sciences Associates, 1981, Lineations associated with surface expression of Calaveras fault between Sunol Valley and Hollister, California: unpublished consulting map for Pacific Gas and Electric, scale 1:24,000.

Hart, E.W., 1980, Fault rupture hazard zones in California: California Division of Mines and Geology Special Publication 42, 25 p.

Hart, E.W., Bryant, W.A., and Bedrossian, T.L., 1979, Observations of fault rupture associated with the August 6, 1979 earthquake, and tabulation of observed data: California Division of Mines and Geology in-house memo of August 6, 1979 to C.F. Armstrong, 6 p., map scale 1:24,000.

Herd, D.G., 1978, Neotectonics of the San Francisco Bay region, California (abstract) in Summaries of Technical Reports, Volume VI: U.S. Geological Survey National Earthquake Hazards Reduction Program, June 1978, p. 16-18.

Kilburn, C., 1972, Ground-water hydrology of the Hollister and San Juan Valleys, San Benito County, California, 1913-1968: U.S. Geological Survey Open-file Report.

Mortensen, C.E. and Johnson, M.J.S., 1976, Anomalous tilt preceding the Hollister earthquake of November 28, 1974: Journal of Geophysical Research, v. 81, no. 20, p. 3561-3566.

Nason, R.D., 1971, Investigations of fault creep slippage in northern and central California: unpublished Ph.D., thesis, University of California at San Diego, 231 p.

Radbruch, D.H., 1968, Map showing recently active breaks along the Hayward fault zone and the southern part of the Calaveras fault zone, California: U.S. Geological Survey Open-file Map, scale 1:24,000.

Radbruch-Hall, D.H., 1974, Map showing recently active breaks along the Hayward fault zone and the southern Calaveras fault zone, California: U.S. Geological Survey Misc. Investigations Series Map I-813, scale 1:24,000.

Real, C.R., Toppozada, T.R., and Parke, D.L., 1978, Earthquake catalog of California, January 1, 1900-December 31, 1974: California Division of Mines and Geology Special Publication 52.

Rogers, T.H., 1967, Active extensional faulting north of Hollister near the Calaveras fault: Bulletin of the Seismological Society of America, v. 57, no. 4, p. 813-816.

Rogers, T.H., 1969, An active fault in the city of Hollister: Mineral Information Service, v. 22, no. 10, p. 159-164.

Rogers, T.H., 1973, Preliminary geologic map of the Hollister and San Felipe quadrangles: California Division of Mines and Geology unpublished map, scale 1:24,000.

Rogers, T.H., 1980, Geology and seismicity at the convergence of the San Andreas and Calaveras fault zones near Hollister, San Benito County, California: California Division of Mines and Geology Special Report 140, p. 19-28.

Rogers, T.H., (in press), Geologic map of the Hollister and San Felipe quadrangles, California: California Division of Mines and Geology Special Report, scale 1:24, 000 (revision of Roger's 1973 map).

Rogers, T.H. and Nason, R.D., 1967, Active faulting in the Hollister area, in Guidebook to the Gabilan Range and adjacent San Andreas fault: American Association of Petroleum Geologists, Pacific Section, p. 102-104.

Rogers, T.H. and Nason, R.D., 1968, Active faulting in the Hollister area (abstract) in Proceedings of Conference on Geologic Problems of the San Andreas Fault System: Stanford University Publications in Geological Sciences, v. XI, p. 42-45.

Rogers, T.H. and Nason, R.D., 1971, Active displacement on the Calaveras fault zone at Hollister, California: Bulletin of the Seismological Society of America, v. 61, no. 2, p. 399-416.

Savage, J.C., Speith, M.A., and Prescott, W.H., 1976, Pre-seismic and coseismic deformation associated with the Hollister, California earthquake of November 28, 1974: Journal of Geophysical Research, v. 81, no. 20, p. 3567-3574.

U.S. Geological Survey, 1966, Aerial photos WRD 4449 to 4465 and 4523 to 4527, black and white, vertical, scale approximately 1:12,000.

U.S. Geological Survey, 1974, Aerial photos 12-134 to 142, low sun angle color, vertical, scale approximately 1:22,000.

U.S. Soil Conservation Service, 1939, Aerial photos BUX - 243 - 6 to 10, black and white, vertical, scale approximately 1:22,000.

5. Review of available data, air photo interpretation, and field checking

Calaveras Fault

The Calaveras fault depicted on the 1974 Special Studies Zones (SSZ) Map of the San Felipe 7.5-minute quadrangle is based on mapping by Radbruch (1968) and Rogers (1973) (figure 2). A more current map by Radbruch-Hall (1974) depicts the Calaveras fault essentially the same as the previous 1968 map. Fault locations of Radbruch (1968) and Radbruch-Hall (1974) generally were compiled from Rogers and Nason (1967). A revised map of the San Felipe quadrangle by Rogers, currently in press, modifies some locations of the Calaveras fault (figure 3).

The Calaveras fault in the FER study area is a well-defined vertical to near vertical right-lateral strike-slip fault. Historic fault creep is well-documented along this segment of the Calaveras fault (Armstrong and Wagner, 1978; Armstrong and others, 1980; Nason, 1971; Rogers, 1969, 1973; Rogers and Nason, 1967, 1971) (figures 2,4). Right-lateral fault creep averages about 8mm/yr in the city of Hollister to the south and ranges from 14mm/yr to 20mm/yr in the San Felipe quadrangle (Rogers and Nason, 1971)(figure 4).

Historic earthquakes occur frequently along this segment of the Calaveras fault (Real and others, 1978). A M5.9 earthquake occurred August 6, 1979 with an epicenter located near Coyote Lake, 11 km north of the FER study area (Armstrong, 1979). Surface fault rupture associated with the August 1979 earthquake was observed from Anderson Lake south to Hollister. Maximum measured right-lateral offset was about 5mm to 6mm at the intersection of Highway 152 and the Calaveras fault (figure 4). A 2cm to 3cm high east facing scarplet formed in the south shoulder of Shore Road (figure 4). A U.S.G.S. creepmeter station at Shore Road indicated that a total of

14mm of right-lateral strike-slip displacement occurred in a two-week period that started several days before the August 6 event (Armstrong, 1979).

The Calaveras fault is delineated by a relatively narrow zone of sag ponds and associated fault scarps in most of the San Felipe quadrangle (figures 2,3,4). A wider, more complex zone of faulting characterzies the compression ridges in the south part of the San Felipe quadrangle (just west of Hollister airport) and the hills north of San Felipe Lake (Armstrong, and Wagner, 1978)(figures 2,4).

The west branch of the Calaveras fault depicted on the 1974 SSZ map of the San Felipe quadrangle is based on preliminary mapping by Rogers (1973)(figure 2). Subsequent mapping by Rogers (in press) depicts a 3,000 foot-long inferred fault trace north and south of Shore Road (figure 3). Radbruch-Hall (1974) does not map this west branch, and mapping by Earth Sciences Associates (ESA)(1981) does not show the west branch, except for a 1700-foot long trace between Highway 25 and the compression ridge (figure 3).

There is no geomorphic evidence for the location of the west branch of the Calaveras fault, based on air photo interpretation by this writer (figure 4). A vague tonal lineament just south of Shore Road was observed, but well-defined geomorphic fault features are not associated with the tonal lineament. Possible creep is indicated on the 1974 SSZ Map across a bridge along the west branch of the Calaveras fault (figure 2). Rogers (in press) does not show evidence of creep at this location. Evidence of distress to the bridge mandatory of fault creep was not observed during a field check in August 1979 (figure 4). The short fault trace of ESA (1981) coincident with a segment of Rogers' (1973) west branch Calaveras fault is expressed as a very sharp, straight dark line on 1939 USSCS air photos. The tonal linement ends abruptly at a fence line, strongly indicating a man-made feature (figure 3).

Lineaments mapped by Smith (1974) were compiled from air photo interpretation with no field checking (figure 2). The lineaments were not annotated, but seen to be based principally on short, linear segments of drainages that have been modified or straightened by man, based on air photo interpretation and brief field checking by this writer (figure 2). Associated geomorphic features indicating faulting were not observed by this writer.

Well-defined fault traces are located on the West side of the compression ridges west of Hollister airport (figures 2,3,4). Left-stepping en echelon cracks across Highway 25 align with an east-facing scarp in a plowed field to the north and a well-defined linear closed depression to the south (figure 4). The north and west walls of a barn are offset about 30cm right-laterally (Rogers and Nason, 1971)(figures 2,4). The compression ridges seem to be offset right-laterally and evidence for faulting between the two ridges is characterized by somewhat less well-defined geomorphic features including scarps, tonal lineaments and closed depressions (figure 4). ESA (1981), Rogers (in press), and this writer (figure 4) generally agree as to the location of faulting on the west side of the compression ridges, although differences in detail exist (figures 3,4). ESA (1981) indicates faulting on the east side of the compression ridges, but Rogers (in press) maps a concealed fault with no evidence of Holocene activity. No geomorphic evidence supporting Holocene faulting along the east side of the north compression ridge was observed by this writer, based on air photo interpretation and field checking (figure 4). A reservoir north of the northerly compression ridge is assumed to be a sag pond by Radbruch-Hall (1974) and ESA (1981). However, interpretation of 1939 USSCS air photos indicates that this feature has been highly modified by man and may be completely artifical. No geomorphic evidence of faulting is associated with this feature (figure 4).

A wide zone of faulting characterizes the Calaveras fault in the hills north of San Felipe Lake (Armstrong and Wagner, 1978; ESA, 1981; Rogers, in press) (figures 2,3). The main trace of the fault is delineated by well-defined scarps, ponded alluvium, tonal lineaments, and closed depressions associated with a broad sidehill trough. In the NE1/4 of section 12, T11S, R4E (figure 4) geomorphic evidence indicating Holocene faulting west of the main trace includes closed depressions associated with linear troughs, southwest-facing fault scarps, right-laterally offset drainages, a vague sidehill bench, and ponding of alluvium (figures 3,4). Mapping by Armstrong and Wagner (1978), Rogers (in press), ESA (1981), and this writer (figure 4) agrees well along the main trace of the Calaveras fault and along the fault traces about 1000 feet to the west, although differences in detail exist. Possible Holocene faulting just east of Highway 152 is indicated by a closed depression associated with a broad trough, southwest-facing scarps, and disrupted and diverted drainages (Armstrong and Wagner, 1978; Rogers, in press; this report, figure 4).

Historic fault creep, documented on the main trace of the Calaveras fault, is occurring on strands of the Calaveras fault zone west of the main trace, based on survey of fence lines by Armstrong and Wagner (1978) and Armstrong and others (1980)(figure 3). Although problems of soil creep and fence replacement inconsistencies may yield somewhat inaccurate rates of fault creep, it is assumed that some amount of fault creep has offset this fence line with an average rate of about 1cm/yr.

Busch Ranch Fault

The Busch Ranch fault depicted on the 1974 SSZ Map of the San Felipe quadrangle is based on Rogers (1973)(figure 2). Rogers mapped this fault based on the vertical offset of Shore Road and sidewalks on the Busch property, located about 1500 feet west of the Calaveras fault, (Rogers, 1967; Rogers and Nason, 1971; Rogers, in press). Vertical offset measured in 1969 ranged from about 0.5cm to 12cm (Rogers and Nason, 1971). Minor left-lateral offset of 3mm and 11mm was observed in concrete sidewalks, but could not be associated with other fault features (Rogers and Nason, 1971).

A M5.1 earthquake occurred in November 1974, along the southwest projection of the Busch Ranch fault (Savage and others, 1976). Aftershocks of this event defined a linear pattern about 4.0 km long with a northeast trend coincident with the southwest projection of the Busch Ranch fault (Rogers, in press). The preferred fault plane solution was left-lateral strike-slip along a near vertical northeast-trending fault (Rogers, in press). Surface rupture associated with the November 1974 earthquake was not observed along the Busch Ranch fault or its southwest projection (Rogers, in press). Minor north-trending cracks were observed along the

Busch Ranch fault where it crosses Frazier Lake Road after the August 1979 earthquake (Hart and others, 1979). These minor cracks occurred in an unpaved but freshly graded road surface, but no cracks were observed across Shore Road along the Busch Ranch fault (Hart and others, 1979). Thus it is not certain whether cracks crossing Frazier Lake Road were due to shaking effects, or minor surface rupture.

A small (<1m high) northeast-facing scarp can be observed from Shore Road to just south of Frazier Lake Road, based on air photo interpretation and field checking by this writer (figure 4). A subtle tonal lineament can be followed for 2,000 feet southwest of Frazier Lake Road (figure 4). No geomorphic evidence for the short, discontinuous fault traces depicted on the 1974 SSZ Map can be found, based on air photo interpretation by this writer. Rogers (in press) does not map these features (figure 3).

6. <u>Conclusions</u>

<u>Calaveras Fault</u>

The Calaveras fault in the San Felipe quadrangle is a well-defined right-lateral strike-slip fault. A single fault trace through much of the FER study area is delineated by sag ponds, closed depressions, fault scarps, and tonal lineaments (figure 4). Historic fault creep is well-documented along this segment of the Calaveras fault, and ranges from 14mm to 20mm/year (Rogers and Nason, 1971)(figure 2). A more complex zone of faulting characterizes the compression ridges in the southern part of the FER study area (figures 3,4). No geomorphic evidence suggesting Holocene faulting along the east margins of the compression ridges was observed by this writer, based on air photo interpretation and field checking. Rogers (in press) does not map Holocene faulting in this area. Complex faulting also occurs in the hills north of San Felipe Lake (figure 3,4). Well-defined fault traces define the main traces of the Calveras fault in the NE1/4 of Section 12, T11S, R4E (figures 3,4). Additional evidence indicating possible Holocene faulting occurs to the west and is characterized by right-lateral offset drainages, closed depressions, sidehill bench, tonal lineaments, and evidence of historic right-lateral offset of fence lines (figures 3,4). Mapping by Rogers (in press), Armstrong and Wagner (1978), ESA (1981), and this writer adequately delineates well-defined traces of the Calaveras fault.

<u>Busch Ranch Fault</u>

The Busch Ranch fault was mapped by Rogers (1973), based on the vertical displacement of Shore Road and the Busch property (Rogers, 1967). Active deformation along this feature is indicated by the regrading of Shore Road during the period since 1955 (Rogers, 1967). Displacement along the Busch Ranch fault may be caused by susidence due to groundwater withdrawl, but a M5.1 earthquake along the southwest projection of this feature suggests that tectonic deformation is occurring (Rogers, in press). The Busch Ranch fault is well-defined from just north of Shore Road to Frazier Lake Road, and is delineated as a tonal lineament for about 2,000 feet southwest of Frazier Lake Road (figure 4).

7. <u>Recommendations</u>

Recommendations for zoning faults for Special Studies are based on the criteria of sufficiently active and well-defined (Hart, 1980).

<u>Calaveras Fault</u>

Zone for Special Studies well-defined traces of the Calaveras fault shown on figure 5, based on mapping by Rogers (in press), Armstrong and Wagner (1978), Bryant (figure 4, this report), and ESA (1981).

<u>Busch Ranch Fault</u>

Zone for Special Studies well-defined traces of the Busch Ranch fault, shown on figure 5, based on Rogers (in press) and Bryant (figure 4, this report).

8. Report prepared by William A. Bryant, March 4, 1981.

William A. Bryant

I agree with recommendations. make sure historic rupture data are added to Fig. 5.
EWH
3/30/81

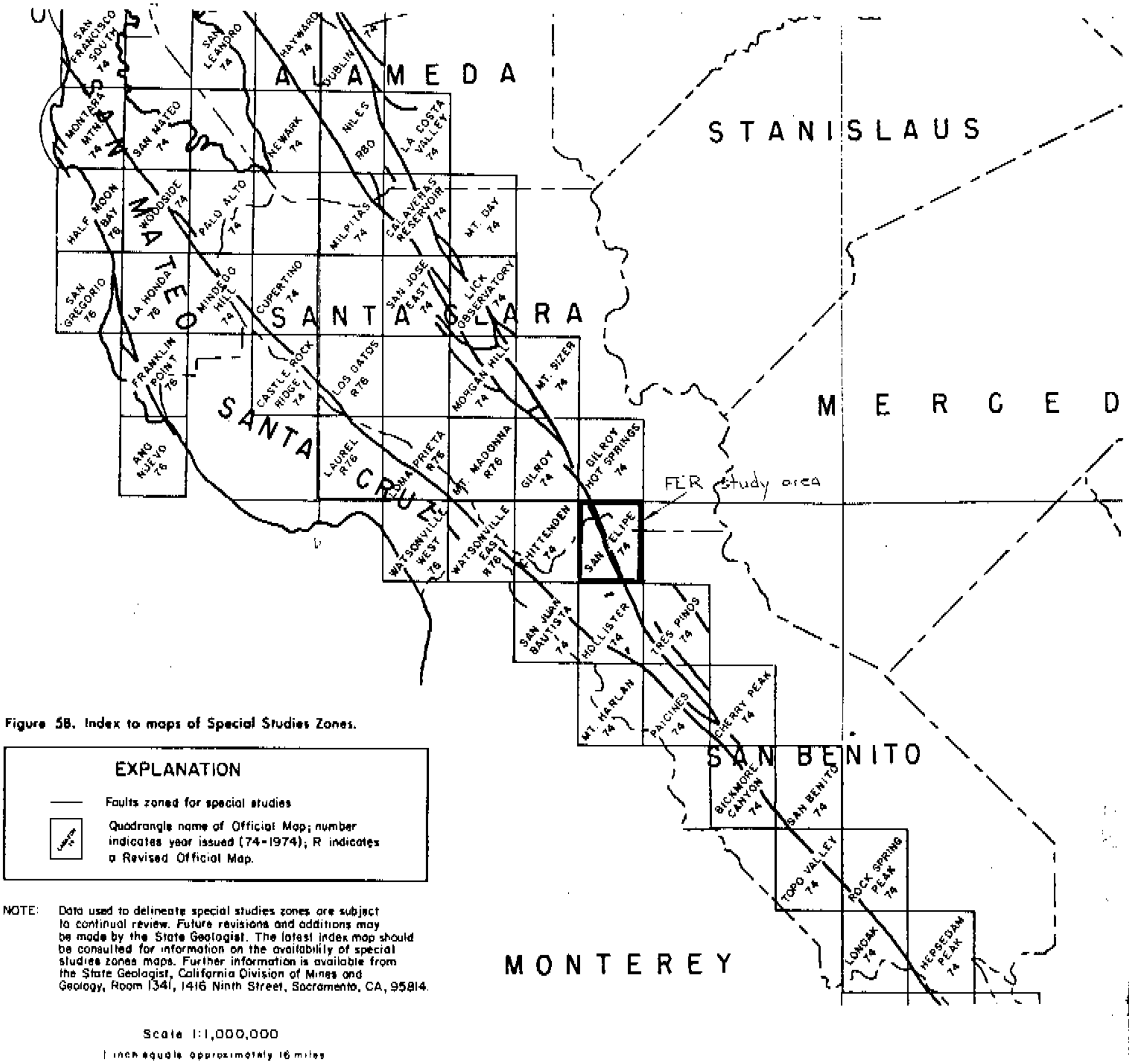

Figure 1 (to FER-114). Location of Calaveras fault zone (shown in green) evaluated in this FER. Map from Hart (1980, p.13).